

**CLAIMS**

1. A system for respiration modulated pacing, comprising:

pulse generator means for generating and delivering pacing pulses to control the beat rate of a patient's heart; and

rate control means for controlling the pacing rate of said pacing pulses, said rate control means further comprising:

respiration means for obtaining respiration signals representative of patient respiration, and modulation means for developing rate modulation signals for controlling said pacing rate to change as a function of said respiration signals so as to increase during the patient's inspiration phase relative to the pacing rate during the patient's expiration phase.

2. The system as described in claim 1, wherein said respiration means comprises sensing means for sensing signals representative of the patient's intrathoracic pressure.

3. The system as described in claim 1, wherein said respiration means comprises signal means for providing a signal indicating the onset of patient inspiration, and said modulation means comprises timing means for timing rate modulation signals to increase pacing rate in response to a said indicated inspiration onset.

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4. The system as described in claim 3, wherein said timing means comprises delay means for delaying <sup>the</sup> an increase in pacing rate following a said indicated inspiration onset.

5. The system as described in claim 1, wherein said modulation means comprises amplitude means for controlling the amplitude of pacing rate change and timing means for controlling the timing of said pacing rate change relative to said patient's respiratory cycle.

6. The system as described in claim 5, wherein said amplitude means comprises cardiac work means for determining a measure of cyclical cardiac work and for controlling said amplitude as a function of said work measure.

7. The system as described in claim 5, wherein said amplitude means comprises volume means for determining a measure of the end-diastolic volume of one of said patient's ventricles and for controlling said amplitude as a function of said volume measure.

8. The system as described in claim 5, wherein said amplitude means comprises pressure means for determining a measure of the blood pressure relating to one of said patient's ventricles and for controlling said amplitude as a function of said blood pressure measure.

9. The system as described in claim 5, wherein said amplitude means comprises maximum rate change means for limiting the change of rate amplitude during a respiratory cycle.

10. The system as described in claim 9, wherein said maximum rate change means comprises body position sensor means for sensing the patient's body position and for limiting said rate amplitude change as a function of said sensed body position.

11. The system as described in claim 9, wherein said maximum rate change means comprises heart rate means for determining a measure of the patient's heart rate and for limiting said rate amplitude change as a function of said heart rate measure.

12. The system as described in claim 5, wherein said respiration means comprises means for determining the onset of patient inspiration, and said timing means comprises means for enabling said modulation means to increase said pacing rate during patient respiration.

13. The system as described in claim 12, wherein said timing means comprises delay means for delaying enablement of said modulation means relative to said inspiration onset.

14. The system as described in claim 1, further comprising means for determining a measure of patient activity, and inhibit means for inhibiting said modulation means

Q47 from changing patient rate as a function of respiration signals when said activity measure exceeds a predetermined reference level.

15. The system as described in claim 1, wherein said pulse generator means comprises means for delivering said pacing pulses to an atrium of said patient.

16. The system as described in claim 1, wherein said pulse generator means comprises means for delivering said pacing pulses to the patient's vagus nerve.

17. The system as described in claim 1, wherein said pulse generator means comprises means for delivering said pacing pulses to the patient's sympathetic nerve system, whereby the patient's heart is paced.

18. A system for pacing a patient's heart, comprising:  
pulse generator means for generating and delivering pace pulses to said heart;  
rate control means for controlling the pacing rate at which said pulse generator means generates and delivers pace pulses;  
respiration means for obtaining respiration signals representative of said patient's respiration, and  
said rate control means comprising modulation means for modulating said pacing rate as a function of said respiration signals.

16 <sup>15</sup> 19. The system as described in claim 18, wherein said respiration means comprises means for determining patient inspiration and expiration, and said modulation means comprises means for increasing said pacing rate during inspiration relative to pacing rate during expiration.

17 <sup>16</sup> 20. The system as described in claim 18, wherein said respiration means comprises means for obtaining signals representative of patient inspiration, and said modulation means comprises means for increasing said pacing rate in response to said signals representative of patient inspiration.

18 <sup>17 further</sup> 21. The system as described in claim 20, comprising rate means for detecting patient sinus rate, and wherein said modulation means comprises means for overdriving said sinus rate during periods of patient inspiration.

19 <sup>18</sup> 22. The system as described in claim 18, further comprising power means for determining a measure of cardiac power output, and wherein said modulation means further comprises means for adjusting pacing rate as a function of said cardiac power output measure.

23. The system as described in claim 18, comprising activity means for obtaining activity representations of patient activity or position, and wherein said modulation means further comprises means for adjusting pacing rate as a function of said activity representations.

24. The system as described in claim 18, comprising pressure means for obtaining pressure representations of the patient's ventricular pressure, and wherein said modulation means further comprises means for adjusting pacing rate as a function of said pressure representations.

25. The system as described in claim 18, comprising volume means for obtaining volume representations of the patient's ventricular volume, and wherein said modulation means further comprises means for adjusting pacing rate as a function of said volume representations.

26. An implantable system for varying a patient's heart rate as a function of the patient's respiratory cycles, comprising:

- a stimulus generator for generating stimulus signals;
- delivery means for delivering said stimulus signals to at least one position within said patient so as to modulate the patient's heart rate;
- respiration means for obtaining respiration signals representative of the patient's respiratory cycles; and
- control means for controlling said stimulus generator to generate said stimulus signals as a function of said respiration signals.

27. The system as described in claim 26, wherein said delivery means comprises vagus means for delivering said signals to stimulate a vagus nerve.

28. The system as described in claim 27, wherein said respiration means comprises means for determining periods of patient expiration, and said control means has means for controlling said stimulus generator to generate stimulus signals during an expiration period.

29. The system as described in claim 26, wherein said control means comprises means for controlling said stimulus generator to generate cardiac pacing pulses, and said delivery means further comprises means for delivering said cardiac pacing pulses to the patient's heart.

30. The system as described in claim 29, wherein said respiration means comprises means for determining periods of patient inspiration, and said control means comprises means for increasing the rate of said pacing pulses during periods of inspiration relative to periods of expiration.

31. A method of pacing a patient to provide a respiration-modulated heart rate, comprising:

obtaining respiration signals representative of the inspiratory and expiratory phases of the patient's respiratory cycle,

generating phasic rate control signals as a function of at least one of said inspiratory and expiratory phases,

generating stimulus pulses at a rate controlled by said phasic

rate control signals, and

Q17 delivering said phasic rate controlled pulses so as to pace the patient's heart at a relatively higher rate during the said inspiratory phase compared to said expiratory phase.

32. The method of pacing as described in claim 31, comprising delivering said phasic rate controlled pulses to the patient's heart.

33. The method of pacing as described in claim 31, comprising delivering said phasic rate controlled pulses to the patient's vagus nerve system.

34. The method of pacing as described in claim 31, comprising obtaining volume signals representative of the patient's right ventricular volume, and generating said phasic rate control signals as a function of said volume signals.

Sub 35. The method of pacing as described in claim 31, comprising obtaining pressure signals representative of the patient's right ventricular blood pressure, and generating said phasic rate control signals as a function of said pressure signals.

36. A pacing system for controlling a patient's ventricular work output comprising:  
sensing means for obtaining a measure of the patient's cyclical ventricular work output;  
variation means for determining variations of said cyclical work

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output;

687 pacing means for pacing the patient's heart at a controlled rate;

and

control means for controlling said rate so as to minimize said variations.

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